Simulating the Impact of Community Culture and Governance in Virtual Innovation Communities

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***Abstract*—There is no substitute to the intellectual disposition to innovate. To increase the value of creative thinking, ideas have to be transformed into wealth production through generation, promotion, and distribution of appreciated products and/or services in a timely and competitive way. To achieve these goals, philosophies of institutions and (virtual) organizations need to be nurtured to promote collective creativity and transformation of ideas into wealth production. The main objectives of the study are to explore and identify design principles for virtual innovation communities and to model innovation as an evolutionary process. A simulation study is conducted to systemically study and generate hypotheses regarding governance mechanisms that improve innovation output. Findings suggest that decentralized coordination schemes such as emergent selection that are observed in utility communities along with moderate degrees of assertiveness and cooperation for conflict management result in higher incidence of innovation.**

I. Introduction

A recent National Academy of Engineering report warned:

> Leadership in innovation is essential to U.S. prosperity and security. In a global, knowledge-driven economy, technological innovation, the transformation of new knowledge into products, processes, and services, is critical to competitiveness, long-term productivity growth, and the generation of wealth.

Creativity is the production of novel and useful ideas by an individual or group of individuals working together [1]. Innovation is an extension of creativity, as it is the successful implementation, adoption, and transfer of creative ideas, products, processes, or services. Although the effectiveness of brainstorming in groups has been researched and debated, little is known about how creative minds interact via group processes [2]. From a process perspective, creativity involves social, cognitive, and technical processes situated in individual, team, and organization contexts that repeatedly produce innovative products. The proposed study answers the call for new methods of studying organizational creativity and innovation [3].

To this end, we present agent simulation of conceptually grounded hypothetical OSS community to test propositions and generate hypotheses pertaining to the impact of (1) governance mechanisms and cultures and (2) conflict management styles of project leadership. Based on the developed model of the hypothetical OSS community, we examine the impact of variation of OSS community culture in terms of their decision-making and coordination styles. We specifically consider three alternative styles that are observed in existing OSS communities: (a) exploration-oriented, (b) utility-oriented, and (c) service-oriented. We then focus on the following questions: What types of coordination and decision-making styles are associated with higher incidence of collective creativity in OSS community projects and which specific conflict management styles improve cyber-enabled innovation?

Observed results reinforce and extend earlier findings on the wisdom of collectives, which suggest that aggregation of decisions of individuals in collectives consistently outperform experts in terms of prediction accuracy concerning likely outcome of future events. When they become stable, utility-oriented communities lend themselves to a climate with higher degrees of boldness and receptivity as compared to exploratory and service-oriented communities, which utilize central or council style decision-making styles. In both the exploratory and service communities, the avoidance (low assertiveness and low cooperation) style in conflict management leads to higher degrees of differentiation in project structure. In the case of low assertiveness and high cooperation style (i.e., accommodation) the project structure becomes well integrated. On the other hand, the integrating style, which is characterized by moderate to high levels of cooperation and assertiveness, performs better in achieving integrated differentiation.

II. Perspective and Background

More than ever the complexity of innovation requires group efforts, as teams of scientists and engineers from diverse backgrounds work together to make discoveries and solve problems. The proposed work aims to contribute to the socio-psychological understanding of innovation in open and virtual innovation communities. The mode of production in such communities involves autonomous contributions, while maintaining the necessary order-by-adjustment to common subject matter of work. For instance, Open Source Software (OSS) communities and scientific communities consist of members that not only work on a common product, but are also aware of this collective work and adjust their actions to new information.

A. Virtual Innovation Communities

Virtual innovation Communities (VICs) such as OSS and scientific communities are suitable candidates for exploring models of innovation, as their mode of production and dynamics align with the characteristics of innovation systems. Individual and collective innovative activities in an innovation system give rise to an evolutionary pattern of technical change. As depicted in Figure 1, virtual innovation communities not only exhibit behavior that explicitly conforms to principles of innovation systems [4], but also follow model of systemic creativity [5]. The components shown in Figure 1 are useful in explaining the innovation processes in scientific and engineering communities. The first component, called the technology context, pertains to technical contributions made by individuals that produce creative solutions to domain-specific problems. Such technical factors induce novel variations in the domains that constitute the scientific context. However, acceptance of variations and innovations in a scientific domain requires the community of scientists and engineers of the organizational context to confirm the appropriateness of the contribution. Hence, it is useful to view the evolution of the science and technology of a specific domain in terms of interactions between the technology, organizational, and scientific contexts.

The systems view of creativity [5] advocates the role of cultural and social environment, as well as psychological dimension in defining creativity. According to the model, for creativity to occur, a set of domain-specific rules and practices must be adopted for an individual to produce a novel and appropriate contribution. The contribution results in a variation in the domain, and it must be selected by the field that represents the society for inclusion in the domain.

Csikzentmihalyi's systems model of creativity [5] shown in Figure 1 captures this phenomena. The model considers *domain* as a critical component of creativity because it is impossible to introduce a variation without reference to an existing pattern specified in the domain knowldge. The technical contributions made by *individuals* that produce creative solutions to domain-specific problems. Such technical contributions induce novel variations in the domains that constitute the context. However, acceptance of variations and innovations in a domain requires the community of scientists and engineers of the *field* to confirm the appropriateness of the contribution. Hence, it is useful to view the evolution of a specific domain in terms of interactions between the individual, domain, and field components.

The mode of production in OSS development as shown in Figure 2 presents structural and behavioral similarities to the systems model of creativity. *Active developers* in such communities freely join and aim to gain ownership of the *project* by proposing patches to existing source code. The project presents to developers opportunities to make contributions and enable them to adjust their actions based on the evolving

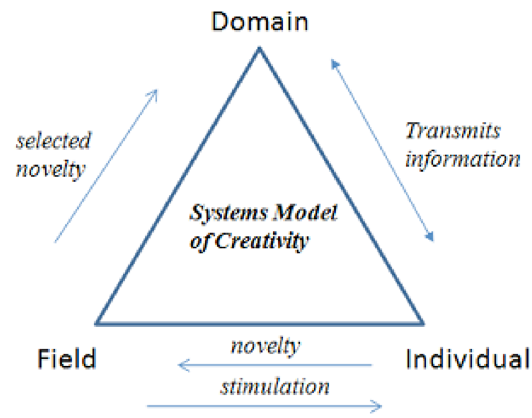


Fig. 1. Systems Model of Creativity.

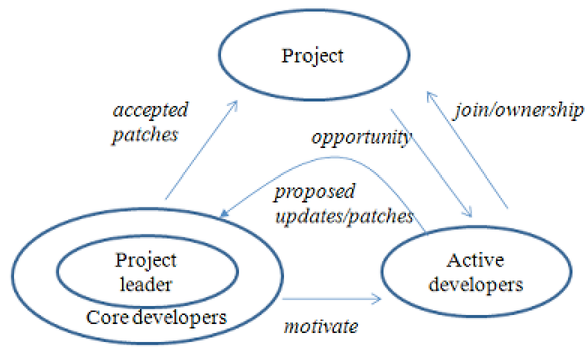


Fig. 2. OSS Mode of Production.

code base that defines the domain knowledge. The proposals are evaluated by the *project leader* along with a small group of *core developers* on the basis of technical merits and elegance of the contributions. Selected contributions are then reflected on the project. The actions of the leader and the core group influence the intrinsic motivation of the participants of projects by affecting the joy and reputation they gain in the process. This strong similarity between the systems model of creativity and OSS mode of production suggests OSS community dynamics and software development process as a useful testbed to study organizational creativity and innovation.

B. VICs are Self-organizing Systems

Complex adaptive systems [6] are composed of autonomous and interacting agents and processes that generate patterns at the macro level to emerge solely from numerous non-linear local interactions among agents at the micro-level. Much of the focus is on how systems of interacting agents can lead to emergent phenomena, which, in our case, is innovation. Self-organizing systems, which are subsets of complex adaptive systems, can best explain the operation of human-engineered innovation systems, where autonomy of individuals is purposefully restricted. The three features of self-organizing systems are (1) the system is composed of units which may individually respond to local stimuli,

(2) the units act together to achieve a division of labor, and (3) the overall system adapts to achieve system goal(s) and objective(s) more efficiently. The mode of operation in virtual innovation communities exhibits such properties, as the individual producers define their own tasks, select and perform tasks through mediated adjustment (adjusting to new directions in development), and integrate solutions via selection through professional attention [7].

OSS communities belong to the same type of virtual innovation communities as scientific communities. Both consist of members who not only work on a common product, but are also aware of this collective work and adjust their actions accordingly [8]. Scholarly analysis of OSS communities has examined why individuals are likely to contribute to such efforts [9], status dynamics [10], and member contribution patterns [11]. OSS communities create informal and formal social structures to manage membership processes, but little has been done to understand governance mechanisms and their impact on the emergence of innovative results.

III. Conceptual Model

OSS communities are specific forms of VICs [12]. The organizational structure of OSS communities is frequently compared to the layers of an onion. Figure 3 depicts the stakeholders and their structural organization. The project leader is often the person, who initiates the project. Core developers are responsible for collective guidance and coordination of the project. Active developers regularly contribute new features and fix bugs. Peripheral developers occasionally contribute new functionality or fix bugs. Their contribution is irregular and the period of involvement is sporadic and short. OSS systems and communities co-evolve through the contributions of large number of participants.

A. Structure

One way to investigate the structure of an OSS community is to view the organization as a social network. A network serves as a locus of innovation because it provides timely access to knowledge and resources that are otherwise unavailable, while also testing internal expertise and learning capabilities. Organizational networks can be characterized along several dimensions such as network design and their process components. On the one hand, higher density networks leads to information sharing (or mobility) which is expected to enhance innovation. On the other hand, higher density networks may lead to the creation of shared norms and conformity and thereby less diversity, which hinders innovation.

B. Dynamics

The evolution of the community occurs as a result of entrance of new members, exit of old members, and role transformation of existing members. In our model, the internal dynamics of an OSS community will be patterned after variation and selection through preferential attachment mechanism presented in [7]. The notion of project leader

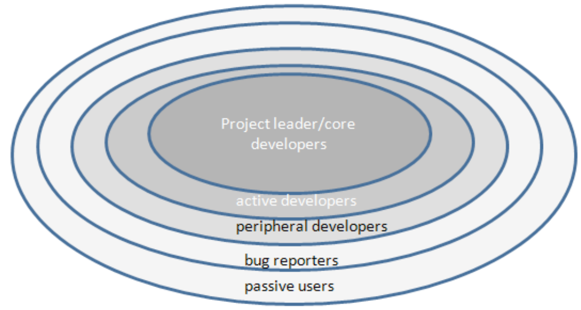


Fig. 3. Community Structure.

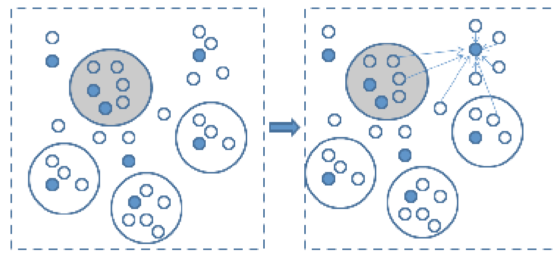


Fig. 4. Reputation - Tagging Mechanism.

”reputation” as a tag for attracting active and peripheral developers and the mechanism of ”imitation” explain which projects developers direct their efforts. In Figure 4 small dark circles represent the developers with high reputation. Clustering of developers depict subprojects that co-exist with the main threads of development. They may or may not be incorporated into the released public version. When a developer with high reputation and outside a specific cluster develops a new application or thread of development, others are attracted with a probability of success based on the degree of reputation. If developers decide to form a new sub-community, then a new thread in the product domain is instantiated; otherwise, the reputation of the developer is decreased.

The formation of aggregates requires mechanisms for attracting agents toward each other. The notion of tagging is proposed by Holland [13] as a strategy used by agents to perform selective interaction. The evolution of the community occurs as a result of entrance of new members, exit of old members, and role transformation of existing members. In our model, the internal dynamics of an OSS community will be patterned after variation and selection through preferential attachment mechanism presented in [7]. The notion of project leader *reputation* as a tag for attracting active and peripheral developers and the mechanism of *imitation* [7] explain which projects developers direct their efforts. In Figure 5 small dark circles represent the developers with high reputation. When a developer with high reputation and outside a specific cluster develops a new application or thread of development, others are attracted based on the degree of reputation. This may result in one or more independent threads of development. If one development line receives highly respected developers,

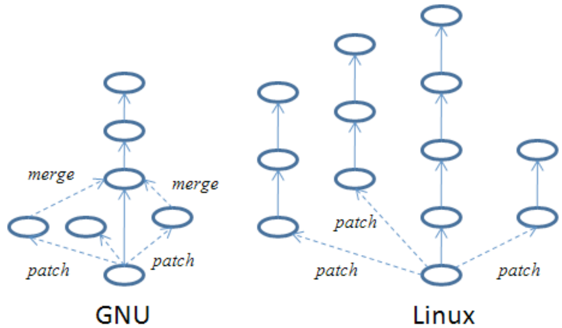


Fig. 5. Project Evolution.

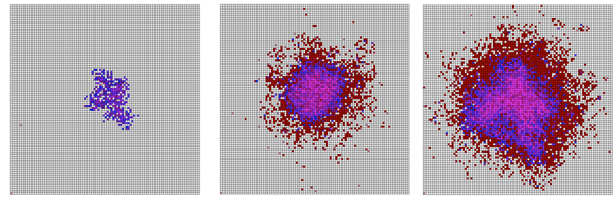
while the second one has fewer and less reputable developers leading the effort, the signaling effect of the reputation tag results in preferential attachment to the project with more reputable developers. This reputation-based tagging notion, along with the imitation mechanism, leads to positive feedback through which one application or development line becomes the dominant one.

This brings us to the dynamics of the domain (software system) evolution. The evolution of the project can be viewed as a bottom-up generative process whereby the core software goes through multiple iterations that improve over time. A plausible perspective is to consider the project to be organized in a tree form, which grows as new subprojects are initiated and patches are created. Figure 5 depicts the evolution style of two popular OSS communities. To simulate the growth of a project, it is necessary to model the effort of individuals along with the evolution of versions (releases) according to a mechanism that mimics the reputation-seeking behavior of individuals. The reward that individuals receive by making contributions to an existing development line or creation of new patches and threads of development should reflect the project preferences of individuals that motivate their involvement in the project. Reputation, as discussed earlier, is a significant factor that influences the actions of developers.

C. Simulation and Preliminary Results

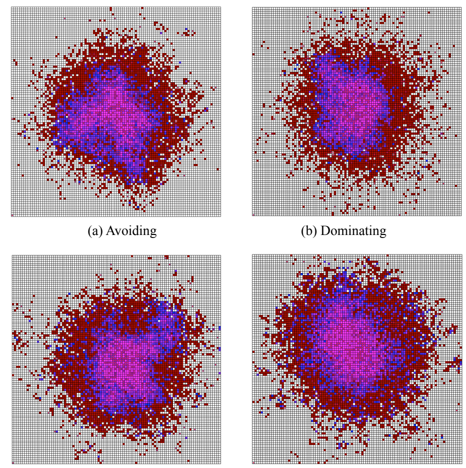
As shown in Figure 6, we simulated a hypothetical OSS community using three factors; culture, conflict management style, and contribution selection criterion. The outcomes of interest in the study are the effects of the identified independent variables (i.e, factors used in the community description) on the degree of differentiation and integration of the domain and the community, as well as the characteristics of the emergent organizational climate as it pertains to collective creativity.

First, the OSS community model is simulated under different scenarios to examine emergent patterns in the project space. These emergent patterns not only provide qualitative insight, but also help achieve face validity to instill confidence in the operational validity of the model. To this end, we look at the evolution over time of the project space of an exploratory community with avoiding style for conflict



(a) time=0 (b) time=500 time=1000

Fig. 7. Project Growth



(a) Avoiding (b) Dominating (c) Integrating (d) Obliging

Fig. 8. Exploratory Community

management. Figure 7 presents the snapshots of the projects at time t=100, 500, and 1000.

The blue colored squares indicate modules that have low complexity and maturity. Those modules that attract community members and become complex over time due to acceptance of contributions are represented by the pink squares. The red squares denote new feature requests or requirements that have not yet been confirmed or accepted by the project leadership. As the simulation unfolds, a clear pattern in the project space emerges to depict those areas that receive more attention and attraction. The coherent and unified pattern that starts emerging at time t=500 becomes dissolving and exploration of new paths starts at time t=1000. The structural theme starts disintegrating over time. Figure 8 depicts emergent patterns under exploratory community style with alternative conflict management approach.

In Figure 9, we observe the project space of a utility community when contributions are considered for inclusion based on emergent selection principle, where those contributions that receive sufficient level of attraction and contribution from others are kept within the project to grow. To reinforce our qualitative insight regarding the comparative analysis of the degree of differentiation in project growth across community types and conflict management styles, we compute the entropy in module complexity.

Figure 10 depicts the existence of expected differences and lends support to qualitative observations. The x-axis of

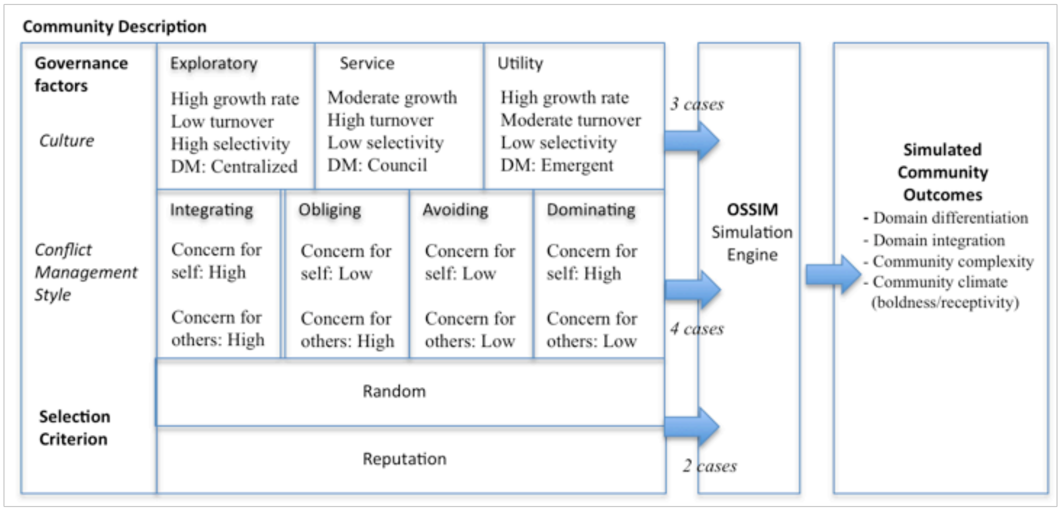
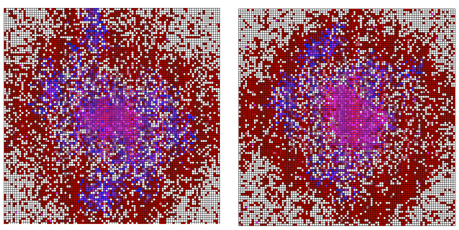


Fig. 6. Experiment Design



(a) Random selection (b) Reputation-based selection

Fig. 9. Utility Community

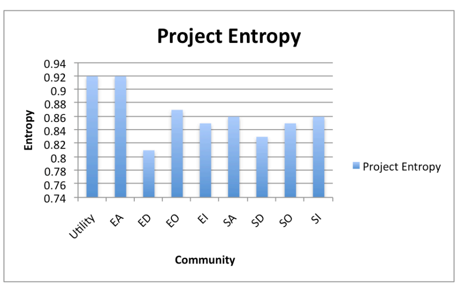


Fig. 10. Entropy Distribution

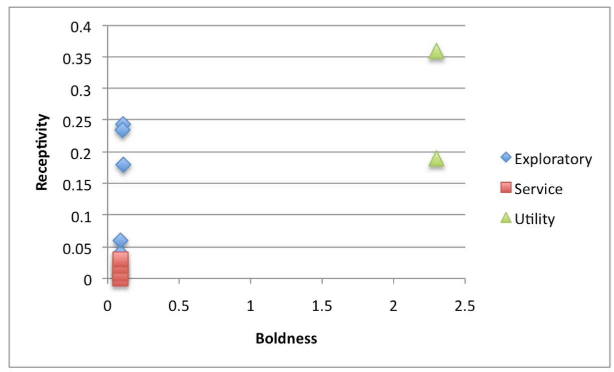


Fig. 11. Boldness-Receptivity Distribution

the chart denotes the community type, where the letters E and S represent exploratory and service-oriented communities respectively. The letters appended to community type indicate the type of the conflict management style (i.e., A-Avoiding, I: Integrating, D-Dominating, and O-Obliging). The y-axis represents the computed entropy.

The results shown in Figure 10 indicate that as expected utility-oriented communities exhibit the highest degree of entropy. This is because either the project is disintegrated and lies within the boundary of complete disorder or it lies at the edge of chaos and order, where incidence of collective creativity is the highest. Given the qualitative insight gleaned from Figure 5, however, we observe that the project growth is not completely disordered and that there exists a pattern that enables the system self-organize at this critical threshold. Another observation is that despite the orderliness of exploratory communities under avoiding style of conflict management, there is significant entropy, hence differentiation within the project space. Also, given the fact that exploratory communities generate projects that are well integrated compared to utility-oriented communities, this result may be indicative of the fact that exploratory communities can be conducive to innovation if proper conflict management style is utilized. Finally, we measure the distribution of boldness and receptivity scores to see whether the qualitative insights above can be reinforced.

In Figure 11, the distribution of boldness/receptivity values for alternative communities is presented. An interesting observation is that for both the service and exploratory communities, the average boldness of the community converges to a fixed small value, while exploratory communities exhibit slightly higher score in terms of receptivity. We also observe that the boldness and receptivity scores for the exploratory and service communities across alternative conflict management styles are clustered and converge to a similar neighborhood in the scatter plot. On the other hand, for utility-oriented communities both the boldness and receptivity levels are significantly higher, suggesting increased potential for incidence of creativity and innovation.

In utility-oriented projects, collective decision making results in significantly better performance compared to exploratory and service communities. Therefore, overall, the results tend to support the expectation that emergent selection, by which the community decides which contributions are novel and useful, lead to higher incidence of creativity. This is similar to the notion of collective wisdom in decision making within prediction markets where the prediction accuracy tends to be higher when a community uses a market mechanism to make forecasts about the likelihood of outcomes for future events. When a group of community members as part of the project leadership submits votes on the acceptability of a contribution with equal weights reflecting the degree of their interest to the functional area in which the contribution is submitted, the boldness and receptivity values tend to be minimized. This suggests rigid control over the project growth is likely to lead stagnation in divergent thinking.

IV. Conclusions

The view advocated in the study is that innovation communities exhibit the characteristics of self-organizing complex adaptive systems and the tools in complexity science can bring useful insight into the study of creativity and innovation. To this end, we developed a model for representing the structure and dynamics of OSS development communities. A strong analogy between the mode of production in OSS ecologies and systems model of creativity is substantiated and the processes underlying the systems model of creativity is realized within the context of OSS development. Findings suggest that decentralized coordination schemes such as emergent selection such as found in utility communities and moderate degrees of assertiveness and cooperation for conflict management result in higher incidence of innovation.

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